THE UNIVERSITY OF ALBERTA

THE RELATIVE EFFICIENCY OF SELECTED COUPLING AGENTS USED IN THERAPEUTIC ULTRASOUND

BY

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "The Relative Efficiency of Selected Coupling Agents Used in Therapeutic Ultrasound" submitted by Garnet E. Cummings in partial fulfilment of the requirements for the degree of Master of Science.

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ABSTRACT

The purpose of this study was to determine the degree to which each of a selected sample of commonly used coupling agents assists in the transmission of ultrasound of eight hundred and seventy kilocycles emitted over a range of predetermined intensities.

The five coupling agents chosen for the study were: thixotrophic gel, glycerine, distilled water, cardiac cream, and liquid petroleum. The procedure was separated into three phases; pre-test, in-test, and post-test. The pre-test procedures included preheating the coupling agents to 21 degrees centigrade, fixing the receiver head to the head housing, and allowing the transmitter to warm-up for two minutes prior to the start of each test day. The in-test procedures included applying the coupling agent to the surface of the receiver, placing the transmitter head in the housing such that the two heads were in direct vertical and horizontal alignment, and finally setting the desire intensity of the ultrasound unit. The order for testing the coupling agents was determined by the latin square technique. The post-test procedures involved dismantling the heads from the head housing, cleaning and cooling them and cleaning the head housing of all residue coupling that may interfere with further measurements.

This study was a 5 x 5 factorial design utilizing descriptive statistics to analyze the results. The results indicated that at all

five intensities, (0.7, 1.4, 2.1, 2.8 and 3.5 watts per square centimeter continuous wave) the ranking of the coupling agents on their ability to transmit sound are listed in order of efficiency: thixotrophic gel, glycerine, distilled water, cardiac cream, and liquid petroleum.

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

Since the inception of ultrasound as a therapeutic modality by Wood and Loomis (1) in 1927, the physical and biological effects of this high frequency sound apparatus have wond wide acclaim in Europe, accompanied by a rapid integration of ultrasonic therapy into Germany, France and England. World War II stimulated further research in the area of ultrasonics and related subject areas. The results of this research were most vigorously felt in Germany, Switzerland, France, Italy, Austria and North America (2).

Specifically ultrasound is a therapeutic modality utilizing a frequency of one thousand kilocycles or eight hundred and seventy kilocycles. The average intensity used in clinical practices is between 0.5 and 3.0 watts per square centimeter. By definition, the average intensity in watts per square centimeter is the total output in watts divided by the effective radiating area in centimeters (3).

The characteristics of ultrasound waves and common radio waves are very similar. The only real difference is in the frequency of the two waves. Generally, ultrasound waves are transverse waves of condensation and rarefraction that are beamed in a longitudinal fashion. The divergence of the beam is inversely proportional to the frequency and the frequency is inversely related to penetration (3).

At present, there are many and varied coupling agents, but information concerning their efficiency is not so readily available since research in this area is just beginning to develop.

Many studies have investigated the effects of ultrasound at the cellular level (4,7,8,9). Some concluded that ultrasound has some very profound effects on the exposed area and that the intensities of the treatment are crucial in affecting regeneration in the healing process (4,5,6). In all of these studies, a coupling agent was used to enhance the transmission of sound into the skin surface or more specifically, to exclude the air. However, the relative efficiency of the various coupling agents in completing the above objective have only casually been questioned. Through discussion with a number of people in the field of physiotherapy, there appears to be practical but no scientific reasons for using one coupling agent over another. Some of the practical reasons put forth are: availability of coupling agents, shape of the area to be treated, the personal preference of the therapist, cost of the coupling agent, and the viscosity of the coupling agent.

Problem

The purpose of this study was to determine the degree to which a selected sample of commonly used coupling agents assists in the transmission of ultrasound of eight hundrea and seventy kilocycles emitted over a range of predetermined intensities.

Limitations

1. This study is limited by the exclusive use of coupling agents as found in the clinical setting.

2. The intensity settings used in the study are those within the clinical range.

3. The time limit of exposure for each coupling agent is five minutes. This time was selected since it was most frequently reported in the literature (7,9).

4. The statistical analysis of the study is limited to descriptive statistics.

Definition of Terms

1. Impedance - is the total resistance offered to and alternating current.

2. Thixotrophy - is a property possessed by some liquids that when exposed to shear forces they exhibit a decrease in viscosity.

Hypothesis

The following null hypothesis is assumed throughout the study:

1. There is no difference in the sound conduction qualities of the various coupling agents - symbolically, $U_1 = U_2 = U_3 = U_4 = U_5$.

Assumptions

Assumptions followed throughout the study are:

1. The greater the difference between the output from the

generator and the amount of sound received, the less the efficiency of the coupling agent as a transmission medium for sound.

2. The intensity of sound transmitted as indicated by the intensity meter on the ultrasound machine is directly proportional to the voltage output on the transmission beam of the oscilloscope and equal to the amount emitted from the transmitter head.

3. Since the transmission and receiving heads are only three decimal one five (3.15) millimeters apart, it is assumed that the divergence of the sound wave at the frequency of eight hundred and seventy cycles per second is negligible.

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CHAPTER II

REVIEW OF LITERATURE

Throughout the last three decades there has been a vast amount of literature, pertaining to ultrasonics and related subject areas, presented in various journals (e.g. Archives of Physical Medicine, and Journal of the American Physical Therapy Association). Only those studies which are directly related to the topic of thermal or non-thermal effects of ultrasound were reviewed.

Thermal Effects of Ultrasound

Within therapeutic limits ultrasound is considered a mechanical agent. However, some of the mechanical vibrating energy is converted to heat. The results of mechanical and thermal energy are secondary biological and chemical effects. This thermal energy is relatively small at low intensities, but may be considerable at tissue interfaces. The heating that occurs at bone-periosteal interfaces may be sufficient to cause periosteal burning. The discomfort from deep structures, secondary to heating, is a limiting factor in dosage levels.

Kobak (7) made the following statements comparing the propogation of heat in ultrasound and diathermay,

> Among the factors recognized as fundamental to the interpretation of ultrasonic energy is the genesis of a colaric phenomenon, that on the basis of a superficial resemblance to the thermal effects of diathermay has been erroneously confused with the latter.

The difference in the two modalities lies in the fact that thermo energy used in diathermay is generated by polarity movement whereas the generation of heat in ultrasound is by mechanical means.

Research has indicated that there are three phenomena that occur at this interface. The first one is reflection which occurs when there is a mismatch of impedance between two tissue layers (1). Refraction is the second phenomenon and it involves the bending of the sound wave as it passes from one medium to the next (1). Thirdly, absorption, is directly related to heat production. Heat is generated in any medium by ultrasound due to the natural impedance of the medium (7). Since ultrasound is capable of producing a rise in temperature it follows that the usual physiological effects of heat would also occur. Specifically, many of those physiological responses have been investigated in order to determine the exact reasons for their occurance (3,4,5).

Lehmann and his co-workers (6) found that application of ultrasound produced a selective rise in temperature resulting from selective absorption by the various body tissues. On the basis of his findings, Lehmann further stated that it was feasible to heat, to any desired degree, important structures such as synovial membrane and joint capsule. Lehmann (6) also noted that the temperature distribution throughout soft tissues was critically dependent on the temperature of the coupling medium. The results indicated that the coupling agent must be maintained at 21 degrees centigrade or slightly less in order to produce the highest temperature in the structures adjacent to the bone.

Dunn (8) studied the effects of temperature on the absorption coefficient. The results indicated that when the spinal cords of young mice were heated to varying temperatures and exposed to ultrasound, there was a sevenfold increase in the absorption coefficient over a temperature range of 45 degrees centigrade. Dunn concluded that there was a direct relationship between medium temperatures and absorption coefficient of sound.

Gerstein (9) performed a study on the effects of the presence of metal on the temperature rise produced by ultrasound on tissue. Using fresh meat from horses, frogs, dogs and humans, as the media for the sound, ultrasound at one megacycle was used. He (9) concluded that temperature elevations in the region of the maximal ultrasound field were smaller with the presence of metal than with bone at the same depth. It was further concluded on the basis of the results that the presence of metal per se was not a contraindication to the use of ultrasound at therapeutic levels of intensity.

In another study by Gerstein (10) it was reported that there were changes in the threshold of irritability of the nerves leading to eventual complete blockage of impulses. Anderson and others (11), using high intensity dosages (outside the therapeutic range) of ultrasound on the spinal cord and sciatic nerves of rats and dogs, obtained a reduction of action potential leading to complete block and eventually complete irreversible paralysis when the intensity was increased further. As a result of these observations many physicians have applied ultrasound paravertebrally to the corresponding dorsal roots

and to the sympathetic ganglia or chain in order to treat such distal conditions as neuritis and tendinitis. This treatment procedure is termed neurotrophic (12). Zach and his co-workers (13) found that the application of low intensity ultrasound to thoracic paravertebral areas result in rapid decrease in systolic and diastolic blood pressure. In sharp contrast, Paul (14) in his study concerning the thermal effects of ultrasound on reducing vasoconstriction in the extremities, failed to find evidence that could support Zach. This obvious difference was not due to coincidence, but was due to a difference in measuring procedures. In studies dealing with blood flow, some researchers used the skin vessels of the foot as the area for all measurements, while others used the calf areas. The difference in location produced a variety of results due to the difference in the function of the vessels involved. The vessels of the feet are involved primarily in heat dissipation, while the musculoskeltal vessels are involved in metabolic functions (15).

Non-Thermal Effects of Ultrasound

Although most of the studies in the literature deal with heating effects of ultrasound, there have been some studies pertaining to the non-thermal effects. It should be recognized that the following studies cannot be explained exclusively on a non-thermal basis, but tend to include the mechanical, chemical, and biological effects as well.

Dyson and Pond (16) investigated the effects of pulsed ultra-

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sound tissue regeneration, specifically using a rabbit ear. The frequency levels used were 1 or 3 megacycles at intensity ranges of 0.25 to 2.00 watts per square centimeter. The physiological changes produced by the ultrasound included the stimulation of metabolism, vasodilation, and analgesia.

The results indicated that ultrasound at certain dosages has a marked stimulating effect on the growth of new tissue after injury. One of the factors involved in the tissue regeneration was a phenomenon known as streaming (16). This streaming effect was found in conjunction with increased synthesis of collagen resulting in increased growth. Although the above events did occur, it has not been conclusively demonstrated that ultrasound was directly responsible for this growth. Apart from a temporary reduction in the number of mature collagen fibers visible in sonated tissue and some morphological changes within certain fibroblasts, no other significant structural differences have been detected between sonated and control tissue.

In 1965 a series of studies were presented for publication, all of which were concerned with the propagation characteristics of ultrasound in various biological materials (8). The studies, either collectively or independently, concluded that characteristics such as speed of sound and absorption coefficients must be quantitatively known in order to logically apply this form of energy to the alteration and examination of tissue (8).

One such characteristic was frequency dependence. According to Goldman and Hueter (17) the absorption per wave length of a given

tissue was generally constant over the frequency range considered (0.1 to 50 megacycles). This point was illustrated by the fact that as the absorption coefficient of fat exposed to one megacycle and a ten megacycle machine, the sample exposed to the ten megacycle machine had a higher absorption coefficient.

The findings of Hueter and Goldman were supported by Carstensen (19) who concluded, that as frequency is increased, the depth of penetration is decreased. Therefore Carstensen recommends that a one megacycle machine be used in therapeutic situations.

According to Patrick (18) the choice of frequency is either one megacycle or three megacycle machine. The higher the frequency the greater is the absorption of the ultrasound as it passes through the body tissues. Therefore if one desired to increase the absorption for a particular skin load, a higher frequency machine would be used (three megacycles).

However, this relationship does not hold as strictly when using liquids as compared to fat. Classical viscous absorption results from the face that liquids exert a finite resistance to shearing forces such that changes in density are not in time phase with changes in pressure (13). To support Patrick, Griffin and his co-workers (20) performed a study to determine the contrasting effects of different frequencies of ultrasound radiation on the depth of penetration and found that the lowest frequency machine gave a significantly greater amount of pain relief due to the depth of penetration.

The second characteristic was that of amplitude dependence.

The procedure used to determine the relationship between amplitude and absorption coefficient was developed by Hueter (21). The procedure consisted of placing small thermocouples in the tissue then exposing the specimen to ultrasound of known amplitude and velocity. He measured the initial rate of temperature change associated with the phase of the response brought about by the absorption in the material surrounding the thermocouple was measured. Hueter concluded from his results that in the range of amplitudes employed in his study, the absorption coefficient was dependent on the intensity of the incident wave. He further concluded that each medium has a natural absorption coefficient. When this coefficient was determined by measuring temperature, there was a direct linear relationship between amplitude and temperature increase. This individuality exhibited by various media was investigated by Schwann and Carstensen (22) who maintain that the molecules of a given medium travel at a velocity which is characteristic of the properties of that medium. Further, the velocity of sound is a constant of the medium and independent of sound amplitude. The transmission properties of a given medium are completely specified by its impedance. Impedance is acquired by the product of the specific velocity of sound and the density of the medium. Schwann and Carstensen have found that when a sound wave strikes the interface between two different media, a portion was transmitted and a portion reflected. Ludwig (23) supports the findings of Schwann and Cartsensen in stating that approximately forty per cent of the energy from the source will be transferred to water or tissue, but less than one one hundredth of one per cent passed

from quartz to air and one tenth of one percent from air to tissue. Thus, it was apparent that air spaces must be avoided if the treatment is to be effective.

In reference to intensity and impedance, Patrick (18) stated:

> The reduction of the intensity of ultrasound when passing through soft tissue has been assessed experimentally and the result is expressed as a half-valve layer, that is a layer at which the skin intensity is reduced by 50%.

While discussing the non-thermal effects of ultrasound, Griffin (24) constructed a table illustrating the relative effects of protein on sound absorption and depth penetration. In this context penetration was synonymous with transmission. Griffin further stated that absorption was inversely related to penetration. With the above assumption in mind, Griffin made the following conclusions;

Firstly, water was low in sound absorption and high in penetration or sound transmission; secondly nerve tissue illustrated a high degree of absorption and a low degree of sound transmission while having a high protein content. Griffin concluded sound transmission is inversely proportional to protein content.

In contrast, to the above statement by Griffin, Kobak (7) concluded the quality of acoustic heating action was essentially a non-specific character, having no selective affinity for any cell or tissue.

In summary, it appears evident from the literature that the thermal and non-thermal effects of ultrasound are plentiful and well documented. Not all effects are known and therefore investigation is

required concerning the inter-relationships of the above effects. However, there are some specific points that have been brought forward. Firstly, the depth of penetration is relative to the frequency of the machine. Secondly, the treatment time is relative to the amount of area being treated (five minutes for an area up to twice the area of the treatment head). Thirdly, the intensity decreases as it passes through the tissue according to the half-valve layer theorem and the inverse square law. Finally, the prime purpose of a coupling agent is to exclude air.

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CHAPTER III

METHODS AND PROCEDURES

Apparatus

The transmitter, an ultrasound unit*, was a device that operated at eight hundred and seventy kilocycles utilizing a ceramic transducer. The receiver was a frequency and impedance matched quartz crystal, from an identical sound head, as was used for the transmitter. This arrangement was chosen in order to negate this part of the apparatus as a source of error. The sequence of events leading up to the reception of the sound involves the electrical distortion of the quartz crystal housed in the transmitter head, which emits sound waves. These sound waves in turn distort a quartz crystal, housed in the receiver. The receiver and the transmitter were both connected to a dual beam oscilloscope.

In addition, a water bath was used to maintain the coupling agents at a constant temperature. The water bath was equipped with a mercury thermometer in order to check the water bath temperature. Furthermore, a thermocouple was used to check on the temperature of the coupling agents prior to testing.

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*Burdick UT 4300

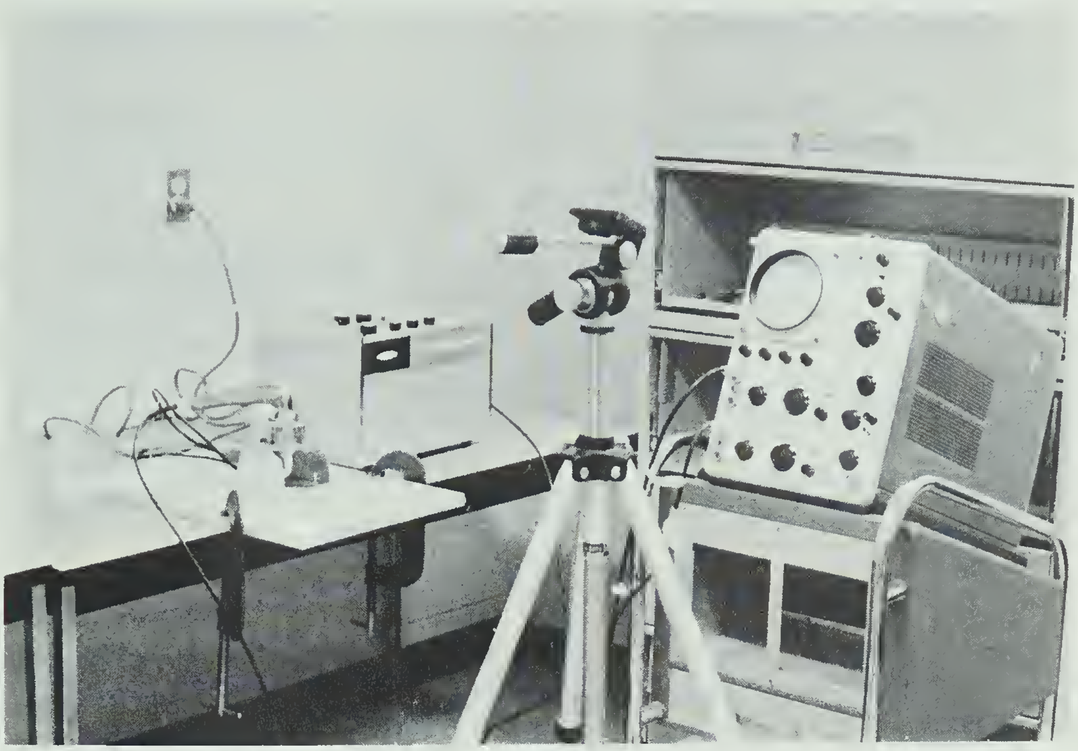

FIGURE 1 ILLUSTRATION OF RESEARCH APPARATUS

Finally, the coupling agents that were used in the study were: distilled water, petroleum gel, mineral oil, thixotrophic gel*, and electrocardiograph paste.

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*Aquasonic 100 Gelatin Burdick Corporation, Milton, Wic.

TABLE I

CATEGORIZATION OF THE SELECTED COUPLING AGENTS

Coupling Agent	Category
Aquasonic gel	Commercial Agent
Glycerol	Vegetable Oil
E.K.G.	Salt Base
Liquid Petroleum	Mineral Oil
Distilled Water	
Air	

The above mentioned coupling agents were chosen on the basis of their frequency of use in the clinical setting, and because they are representative of a broad category of coupling agents. Also, in order to accurately record the results, a Pentax Camera* was used to photograph the graphical results on the oscilloscope screen.

Experimental Design

This study used a 5 x 5 factorial design where the independent variables were intensity and the coupling agents. The dependent variable was the impedance level of the coupling agent. In order to control any possible sequential effects of continued high frequency sound waves

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*Pentax Spotmatic Camera (35 mm) - Asahi - Optical, Japan.

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on the receiver, the ordering of pairing coupling agent and intensity was determined by the counter balance technique utilizing the Latin Square.

TABLE II

THE PAIRING OF VARIABLES FOR DAY ONE OF THE STUDY

Coupling Agent	Intensity Level (watts per CM^2)				
Distilled Water	.7,	1.4,	2.1,	2.8,	3.5
Petroleum Gel	1.4,	2.1,	2.8,	3.5,	.7
Mineral Oil	2.1,	2.8,	3.5,	.7	1.4
Electrocardiograph paste	2.8,	3.5,	.7,	1.4,	2.1
Thixotrophic Gel	3.5,	.7,	1.4,	2.1,	2.8

Note: The above sequence is duplicated for all five days.

Procedure

The procedure was separated into three phases; pre-test, in-test, and post-test. The pre-test procedures included placing all the coupling agents in a water bath and preheating to a constant 21 degrees centigrade. In order to accurately determine the temperature, the water bath was equipped with both a thermometer and a thermocouple. Other pre-test procedures included the fixing of the receiver to the bottom of the head housing and allowing the transmitter to warm up for two minutes prior to testing.

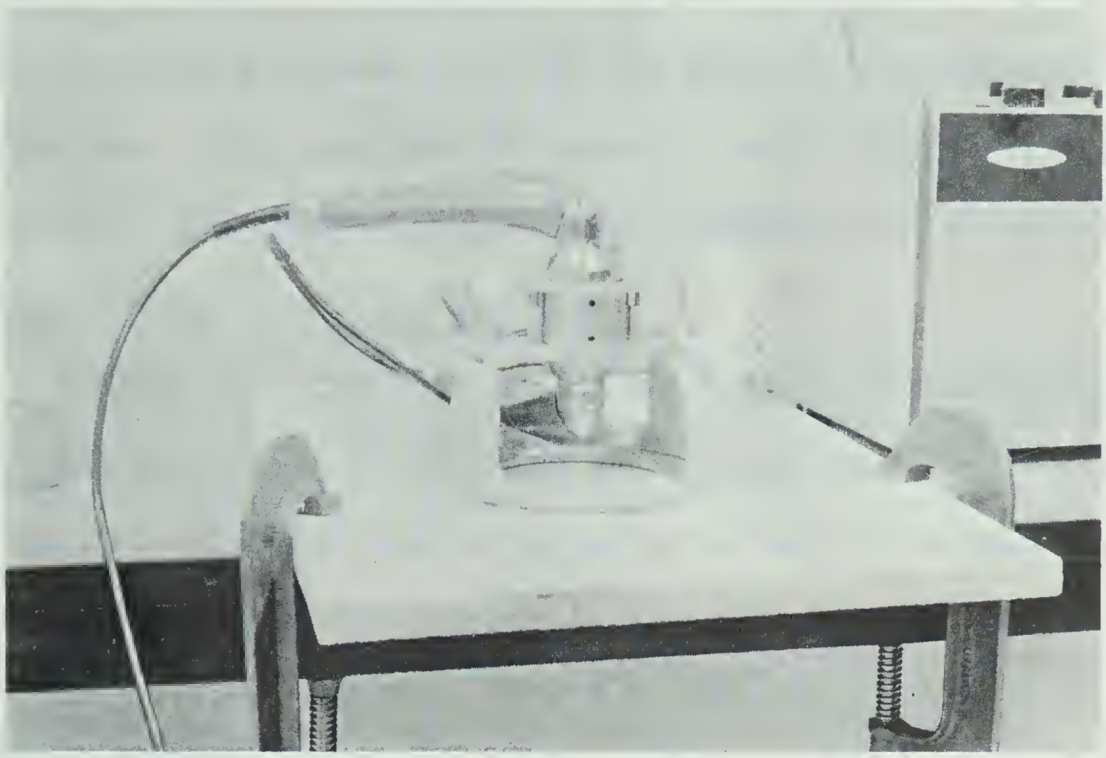

FIGURE 2 THE HEAD HOUSING

The in-test procedures consisted of the following: Firstly, the receiver head was secured to the bottom of the head housing. Next, the coupling agent was applied to the top of the receiver head and the transmitter head was placed in the head housing such that the two heads were in a direct vertical and horizontal alignment located three decimal one five millimeters apart. With the heads in place, the desired intensity was set on the ultrasound machine with the contact switch depressed. When the switch was opened, there appeared on the oscilloscope an electrical interpretation of the transmitted intensity and the reception intensity. At one minute intervals, for five consecutive minutes, a record was made of the transmitter voltages and

the reception voltages as indicated on the oscilloscope. At the five minute mark, a photograph was taken of the results that appeared on the oscilloscope. This was done in order to assist the verification of the results. The above procedures were repeated for all measurements taken from each coupling agent.

Finally, the post-test procedures involved dismantling the heads from the head housing, cleaning and cooling them, and cleaning the head housing such that the accumulation effect of residue from the coupling agents would not invalidate the results.

Statistical Treatment

The statistical treatment to be used was descriptive type statistics, and the results are presented by the use of graphs and tables.

CHAPTER IV

RESULTS AND DISCUSSION

The following results were obtained by converting the raw scores into percentages. These percentages are representative of the quantity of the transmitted sound that was received at each intensity.

The major factors discussed are the comparison of the five coupling agents at the five intensities, the consistences and inconsistencies exhibited by each of the coupling agents as the intensity is increased, and the variation in the results from day to day.

The following tables are comprised of the percentage scores of each coupling agent at each intensity. Each table is accompanied by a line graph illustration of the tabled values. Table III and Figure 3 illustrate the results recorded at the intensity of 0.7 watts per square centimeter.

Table IV and Figure 4 illustrate the results recorded at the intensity of 1.4 watts per square centimeter.

Discussion

The most fundamental observation from the data is the absence of a coupling agent resulting in no transmission of sound using a sensitivity setting of 20 volts per centimeter. Therefore it is con-

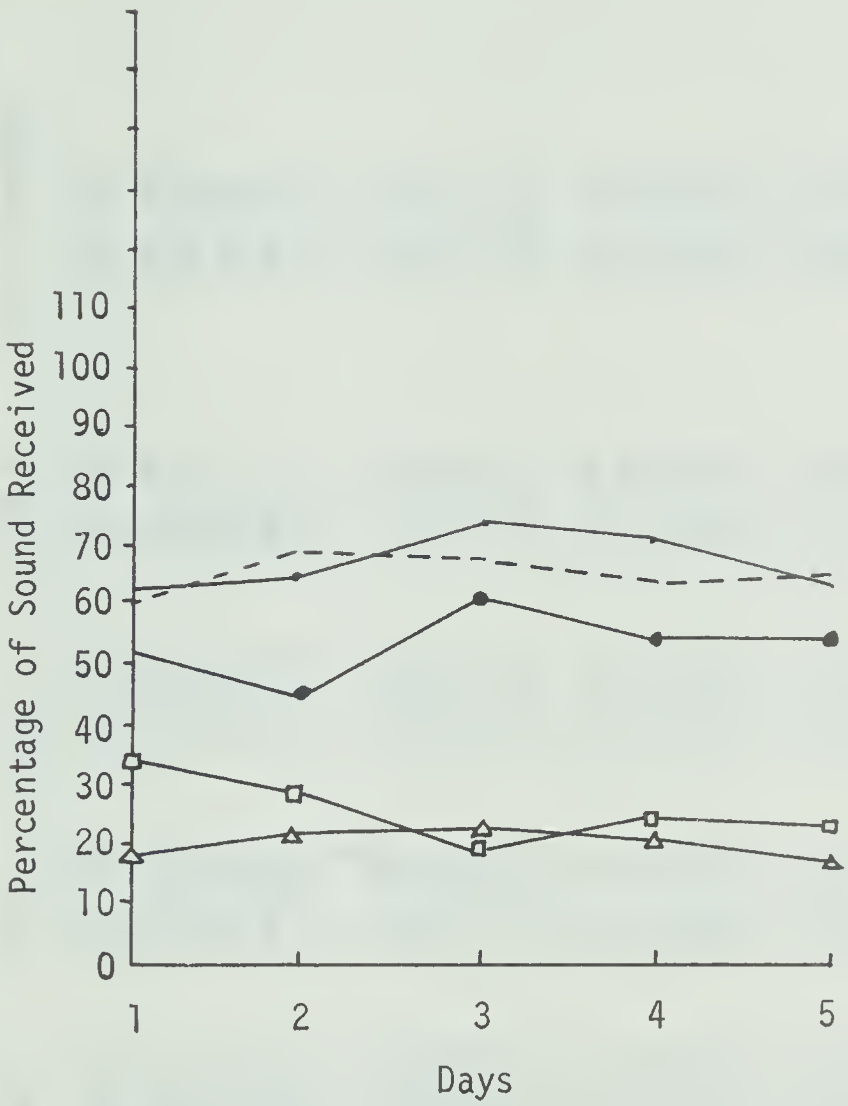

FIGURE 3 THE PERCENTAGE OF SOUND RECEIVED WHEN THE COUPLING AGENTS WERE EXPOSED TO AN INTENSITY OF 0.7 WATTS PER SQUARE CENTIMETER

KEY

Thixotrophic Gel

Glycerine

Distilled Water

Cardiac Cream

Liquid Petroleum

TABLE III

PERCENTAGE OF SOUND RECEIVED AT .7 WATTS PER CENTIMETER SQUARED AT EIGHT HUNDRED AND SEVENTY KILOCYCLES

	Intensity 0.7 watts per square centimeter					
Coupling Agent	Day 1	Day 2	Day 3	Day 4	Day 5	5 day average
Air	00.00	00.00	00.00	00.00	00.00	00.00
Aquasonic Gelatin	63.33	66.67	75.00	72.22	62.86	68.02
	63.33	66.67	75.00	72.22	65.71	68.59
	63.33	66.67	75.00	72.22	65.71	68.59
	63.33	66.67	75.00	72.22	65.71	68.59
	63.33	68.06	75.00	72.22	65.71	68.87
Cardiac Cream	27.78	14.29	17.14	25.00	19.44	20.73
	33.33	22.86	24.29	25.00	22.22	25.54
	33.33	30.00	21.43	26.39	25.00	27.23
	34.72	34.29	17.14	26.39	25.00	27.51
	38.89	37.14	17.14	25.00	25.00	28.63
Distilled Water	51.67	44.12	63.16	55.56	60.00	54.90
	53.33	45.59	63.16	55.56	60.00	55.53
	53.33	45.49	63.16	55.56	56.67	54.86
	53.33	45.59	63.16	55.56	53.33	54.19
	53.33	45.59	63.16	59.26	53.33	54.93
Glycerine	60.98	66.67	69.05	66.67	67.44	66.16
	60.98	66.67	69.05	66.67	67.44	66.16
	60.98	67.86	69.05	66.67	65.12	65.93
	60.98	67.86	69.05	66.67	63.95	65.70
	60.98	67.86	69.05	66.67	66.28	66.17
Liquid Petroleum	18.75	21.88	20.00	21.88	18.75	20.25
	18.75	21.88	20.00	21.88	18.75	20.25
	18.75	21.88	20.00	21.88	18.75	20.25
	18.75	21.88	20.00	21.88	18.75	20.25
	18.75	21.88	20.00	21.88	18.75	20.25
Daily Average	45.93	45.84	49.33	48.52	45.99	47.12

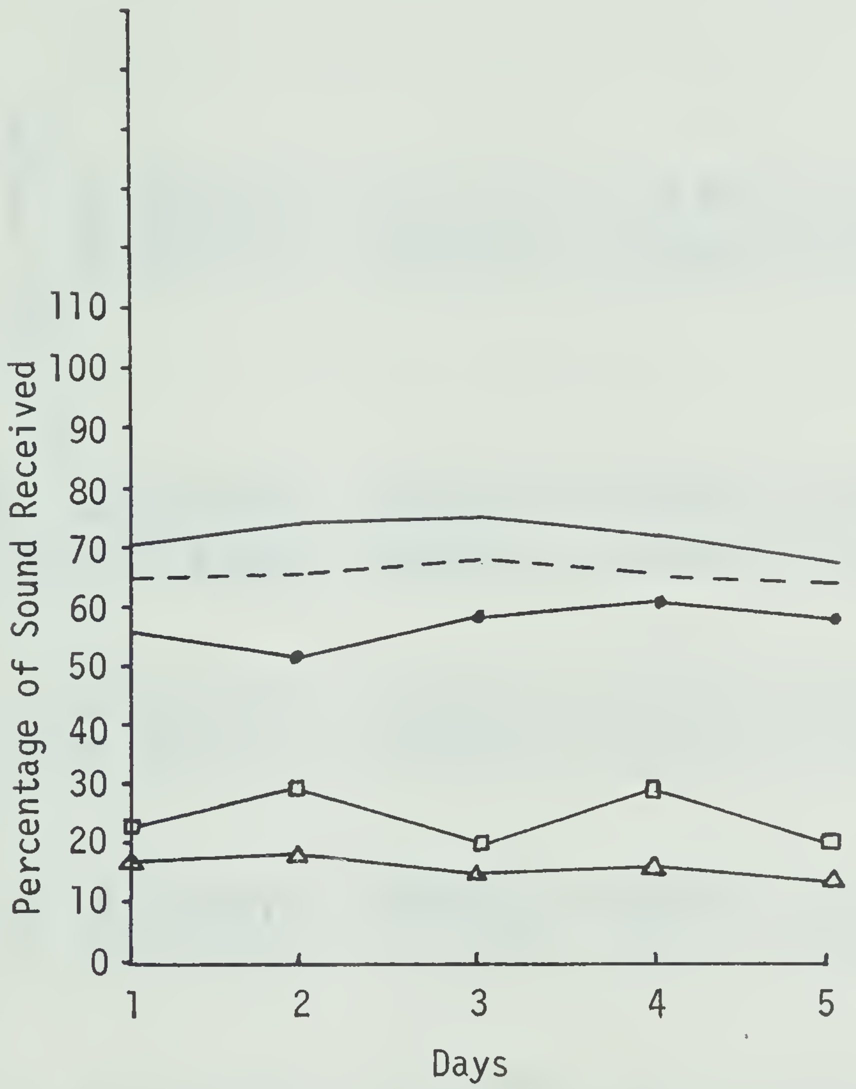

FIGURE 4 THE PERCENTAGE OF SOUND RECEIVED WHEN THE COUPLING AGENTS WERE EXPOSED TO AN INTENSITY OF 1.4 WATTS PER SQUARE CENTIMETER

KEY

Thixotrophic Gel

Glycerine

Distilled Water

Cardiac Cream

Liquid Petroleum

TABLE IV

PERCENTAGE OF SOUND RECEIVED AT 1.4 WATTS PER CENTIMETER SQUARED AT EIGHT HUNDRED AND SEVENTY KILOCYCLES

	Intensity 1.4 watts per square centimeter					
Coupling Agent	Day 1	Day 2	Day 3	Day 4	Day 5	5 day average
Air	00.00	00.00	00.00	00.00	00.00	00.00
Aquasonic Gelatin	70.65	73.91	73.91	72.34	70.65	72.29
	70.65	73.91	73.91	72.34	69.57	72.08
	69.57	73.91	73.91	72.34	69.57	71.86
	69.57	72.83	73.91	72.34	69.57	71.64
	69.57	71.74	73.91	72.34	69.57	71.42
Cardiac Cream	23.26	27.27	18.18	29.55	25.00	24.65
	25.58	29.55	20.45	29.55	25.00	26.03
	24.42	28.41	19.32	29.55	18.18	23.97
	18.60	29.55	18.18	29.55	20.45	23.27
	18.60	36.36	25.00	29.55	21.59	26.22
Distilled Water	57.14	52.31	58.82	62.50	60.00	58.15
	57.14	52.31	58.82	62.50	61.25	58.40
	57.14	52.31	60.00	62.50	61.25	58.64
	57.14	52.31	61.18	62.50	61.25	58.88
	57.14	52.31	61.18	62.50	61.25	58.88
Glycerine	64.00	65.00	69.23	68.00	67.31	66.71
	64.00	66.00	69.23	68.00	67.31	66.91
	64.00	64.00	69.23	68.00	65.38	66.12
	64.00	64.00	69.23	68.00	65.38	66.12
	64.00	64.00	69.23	68.00	65.38	66.12
Liquid Petroleum	17.44	18.60	17.86	18.60	17.44	17.99
	17.44	18.60	17.86	18.60	17.44	17.99
	17.44	18.60	19.05	18.60	15.12	17.76
	17.44	19.77	17.86	18.60	15.12	17.76
	15.12	19.77	19.05	18.60	15.12	17.53
Daily Average	46.04	47.89	48.34	50.20	47.01	47.90

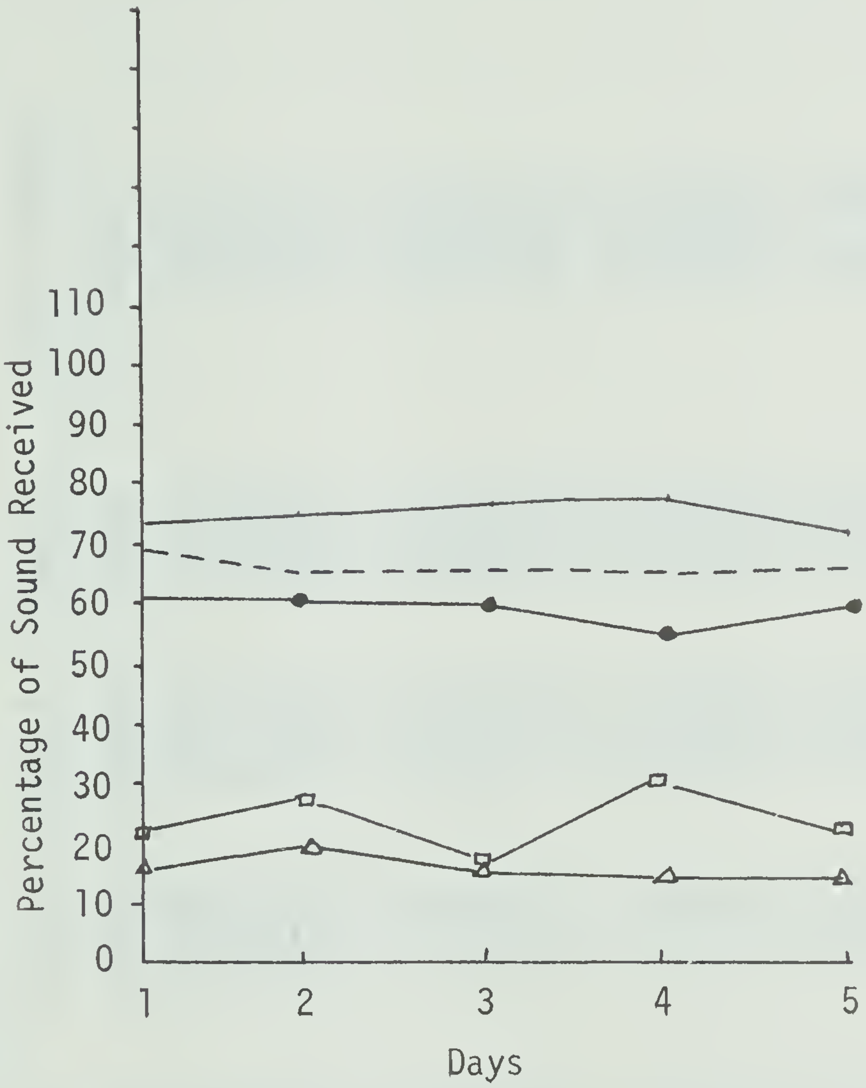

FIGURE 5 THE PERCENTAGE OF SOUND RECEIVED WHEN THE COUPLING AGENTS WERE EXPOSED TO AN INTENSITY OF 2.1 WATTS PER SQUARE CENTIMETER

KEY

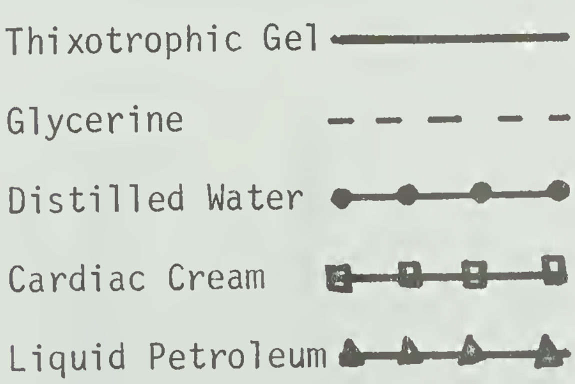

TABLE V

PERCENTAGE OF SOUND RECEIVED AT 2.1 WATTS PER CENTIMETER SQUARED AT EIGHT HUNDRED AND SEVENTY KILOCYCLES

	Intensity 2.1 watts per square centimeter					
Coupling Agent	Day 1	Day 2	Day 3	Day 4	Day 5	5 day average
Air	00.00	00.00	00.00	00.00	00.00	00.00
Aquasonic Gelatin	68.00	73.08	75.00	75.96	71.15	72.64
	74.00	73.08	75.00	75.96	71.15	73.84
	74.00	73.08	75.00	75.96	73.08	74.22
	74.00	73.08	75.00	75.96	73.08	74.22
	76.00	76.92	75.00	75.96	69.23	74.62
Cardiac Cream	21.00	28.00	16.00	32.00	21.00	23.60
	21.00	32.00	17.00	32.00	22.00	24.80
	22.00	32.00	16.00	32.00	23.00	25.00
	22.00	30.00	24.00	31.00	26.00	26.60
	22.00	20.00	22.00	32.00	27.00	24.60
Distilled Water	62.50	61.22	61.22	58.33	62.50	61.16
	61.46	61.22	61.22	58.33	62.50	60.95
	61.46	61.22	61.22	58.33	61.46	60.74
	60.42	61.22	61.22	58.33	61.46	60.53
	61.46	61.22	61.22	58.33	61.46	60.74
Glycerine	68.52	65.45	62.96	66.36	66.67	65.99
	68.52	65.45	66.67	66.36	66.67	66.73
	68.52	65.45	66.67	66.36	66.67	66.73
	68.52	65.45	66.67	66.36	66.67	66.73
	68.52	65.45	66.67	66.36	66.67	66.73
Liquid Petroleum	16.33	18.75	19.15	18.75	16.33	17.86
	16.33	19.79	19.15	18.75	16.33	18.07
	16.33	20.83	19.15	18.75	16.33	18.28
	16.33	20.83	19.15	18.75	16.33	18.28
	16.33	20.83	19.15	18.75	16.33	18.28
Daily Average	48.22	49.83	48.06	50.24	48.04	48.88

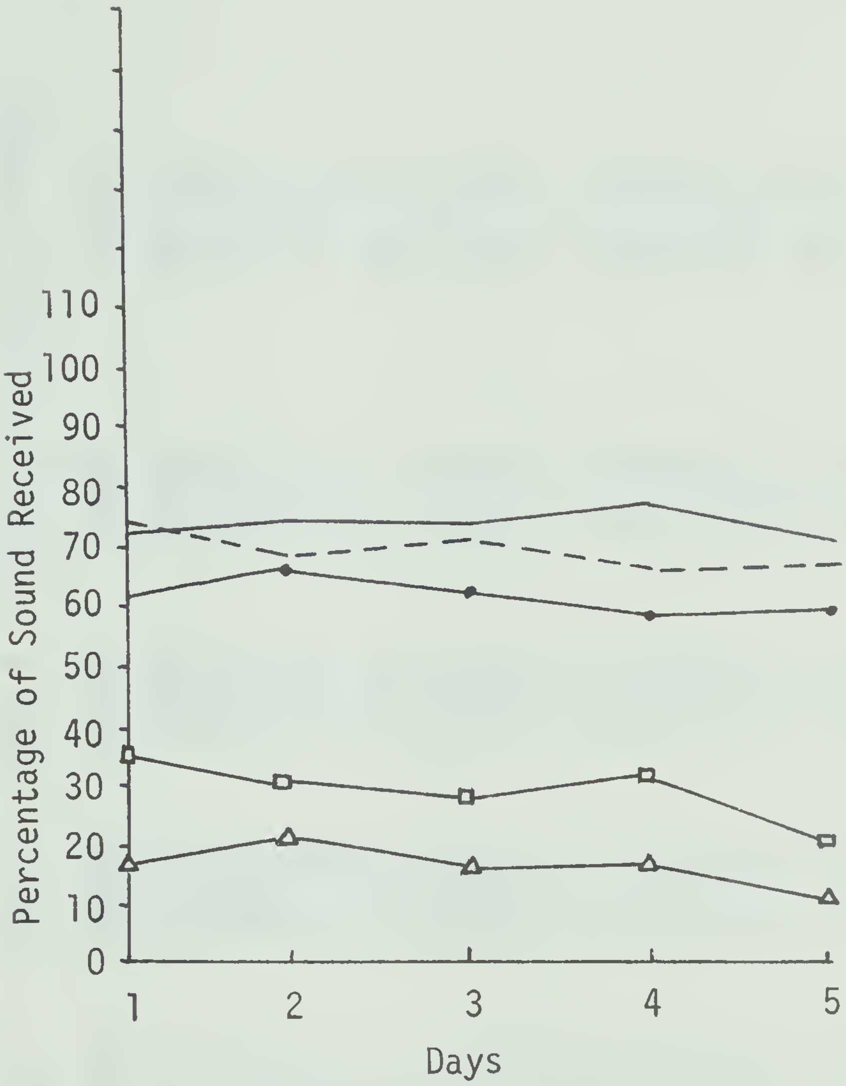

FIGURE 6 THE PERCENTAGE OF SOUND RECEIVED WHEN THE COUPLING AGENTS WERE EXPOSED TO AN INTENSITY OF 2.8 WATTS PER SQUARE CENTIMETER

KEY

Thixotrophic Gel

Glycerine

Distilled Water

Cardiac Cream

Liquid Petroleum

TABLE VI

PERCENTAGE OF SOUND RECEIVED AT 2.8 WATTS PER CENTIMETER SQUARED AT EIGHT HUNDRED AND SEVENTY KILOCYCLES

	Intensity 2.8 watts per square centimeter					
Coupling Agent	Day 1	Day 2	Day 3	Day 4	Day 5	5 day average
Air	00.00	00.00	00.00	00.00	00.00	00.00
Aquasonic Gelatin	72.22	74.07	74.07	75.93	72.22	73.70
	72.22	74.07	74.07	75.93	72.22	73.70
	72.22	74.07	74.07	75.93	71.30	73.52
	71.30	74.07	73.15	75.93	73.15	73.52
	72.22	74.07	72.22	75.93	73.15	73.52
Cardiac Cream	35.85	30.77	25.93	32.69	20.75	29.20
	37.74	31.73	29.63	34.62	22.64	31.27
	37.74	31.73	34.26	34.62	22.64	32.20
	39.62	31.73	31.48	35.58	23.58	32.40
	30.19	32.69	27.78	34.62	23.58	29.77
Distilled Water	63.46	65.38	59.62	63.46	61.54	62.69
	63.46	66.35	62.50	59.62	61.54	62.69
	61.54	65.38	62.50	59.62	61.54	62.12
	61.54	65.38	63.46	59.62	61.54	62.31
	61.54	65.38	64.42	59.62	61.54	62.50
Glycerine	70.37	67.86	71.43	66.07	67.27	68.60
	72.22	67.86	71.43	66.07	67.27	68.97
	74.07	67.86	71.43	66.07	67.27	69.34
	74.07	67.86	70.54	66.07	67.27	69.16
	74.07	67.86	70.54	66.07	67.27	69.16
Liquid Petroleum	17.31	21.57	19.23	17.65	17.31	18.61
	17.31	21.57	19.23	19.61	17.31	19.00
	17.31	21.57	19.23	19.61	17.31	19.00
	17.31	21.57	19.23	20.59	16.35	19.01
	18.27	21.57	19.23	21.57	16.35	19.40
Daily Average	52.21	52.16	51.23	51.32	48.16	51.01

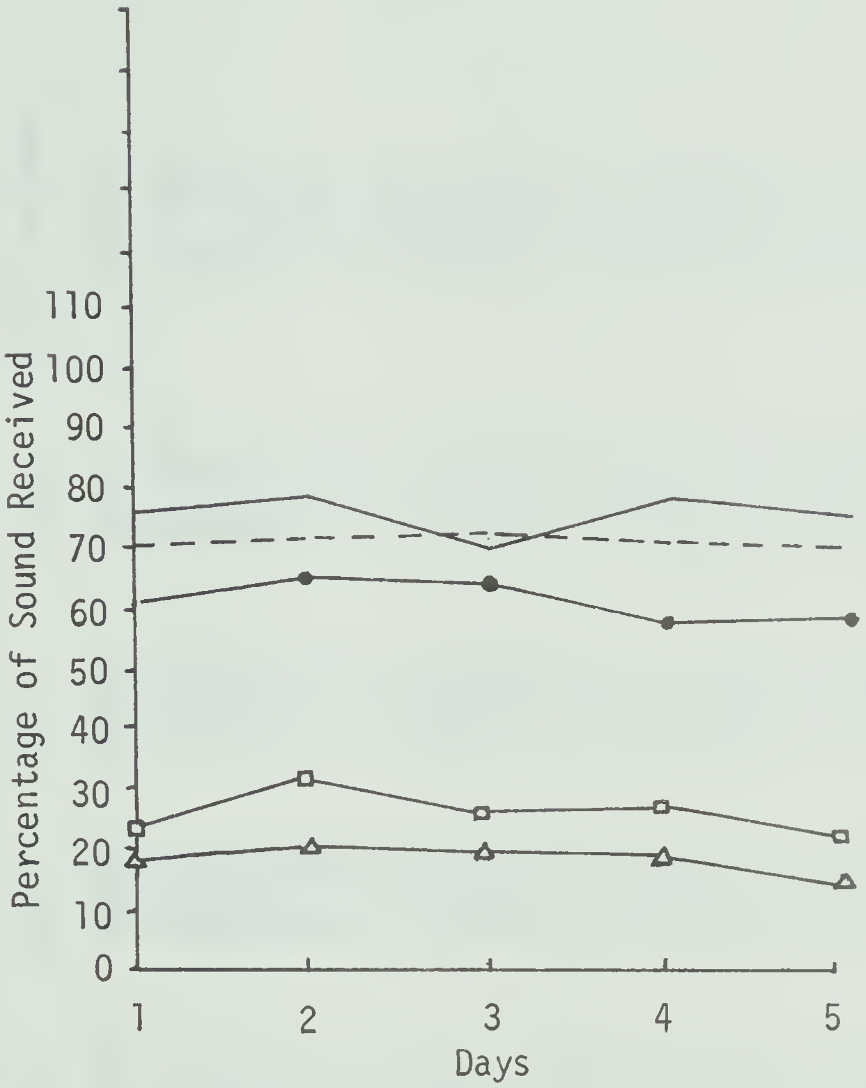

FIGURE 7 THE PERCENTAGE OF SOUND RECEIVED WHEN THE COUPLING AGENTS WERE EXPOSED TO AN INTENSITY OF 3.5 WATTS PER SQUARE CENTIMETER

<u>KEY</u>

Thixotrophic Gel

Glycerine

Distilled Water

Cardiac Cream

Liquid Petroleum

TABLE VII

PERCENTAGE OF SOUND RECEIVED AT 3.5 WATTS PER CENTIMETER SQUARED AT EIGHT HUNDRED AND SEVENTY KILOCYCLES

	Intensity 3.5 watts per square centimeter					
Coupling Agent	Day 1	Day 2	Day 3	Day 4	Day 5	5 day average
Air	00.00	00.00	00.00	00.00	00.00	00.00
Aquasonic Gelatin	75.47	81.65	70.54	76.36	75.93	75.99
	77.36	81.65	69.64	76.36	74.07	75.82
	77.36	80.73	69.64	76.36	74.07	75.63
	75.47	77.06	69.64	76.36	74.07	74.52
	75.47	73.39	69.64	76.36	74.07	73.79
Cardiac Cream	24.07	33.96	31.48	27.78	25.93	28.64
	25.93	32.08	25.93	28.70	22.22	26.97
	22.22	31.13	22.22	28.70	22.22	25.30
	22.22	32.08	29.63	27.78	24.07	27.16
	22.22	32.08	22.22	29.63	24.07	26.04
Distilled Water	62.96	67.92	63.89	62.96	63.89	64.33
	61.11	66.98	64.81	61.11	61.11	63.03
	61.11	64.15	64.81	60.19	59.26	61.90
	61.11	62.26	64.81	57.41	59.26	60.97
	59.26	64.15	64.81	55.56	59.26	60.61
Glycerine	70.37	70.54	70.80	71.43	69.64	70.55
	70.37	70.54	70.80	71.43	70.54	70.73
	70.37	70.54	70.80	71.43	70.54	70.73
	70.37	70.54	70.80	71.43	70.54	70.73
	70.37	70.54	70.80	71.43	70.54	70.73
Liquid Petroleum	19.23	21.15	20.75	21.15	18.87	20.23
	19.23	21.15	20.75	21.15	18.87	20.23
	19.23	21.15	20.75	21.15	18.87	20.23
	19.23	21.15	21.75	21.15	16.98	19.85
	19.23	21.15	20.75	21.15	16.98	19.85
Daily Average	50.05	53.59	50.46	51.38	49.43	50.98

cluded that the primary function of a coupling agent is to exclude air.

The results indicate that the thixotrophic gel was consistently rated as the best conductor of sound at the predetermined intensities and at eight hundred and seventy kilocycles. The sequence of the results (thixotrophic gel, glycerine, distilled water, cardiac cream, and liquid petroleum) was also consistent at all intensities and on all five days. This is a strong argument for the reliability of the results.

In an attempt to make the results more meaningful, a test for density was performed on each coupling agent. These results are listed in Table VIII.

The procedure for the density was as follows:
The densities of water and glycerol are standard values (1). The densities of the remaining three substances were determined using pyknometers of known volume, calibrated at 20 degrees centigrade (68°F); room temperature was 21 degrees centigrade (70°F). The value determined for aquasonic must be considered to be a minimum value only, as its high viscosity made it difficult to remove all the air bubbles; however, the estimated error is not greater than one per cent.

It is evident from Table VIII that the density of the coupling agents may be part of the reason for the variation in percentage scores exhibited by these coupling agents. The order indicates the density

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(1) Handbook of Chemistry and Physics, 49th edition, The Chemical Rubber Company, Cleveland, Ohio, (1969).

TABLE VIII

THE DENSITY OF THE FIVE COUPLING AGENTS

Coupling Agent	Density
Glycerine	1.261 grams per cubic centimeter
Thixotrophic Gel	1.135 grams per cubic centimeter
Distilled Water	1.000 grams per cubic centimeter
Cardiac Cream	0.961 grams per cubic centimeter
Liquid Petroleum	0.872 grams per cubic centimeter

is inversely proportional to conduction quality of the coupling agent. This may be explained by the fact that as the materials become more dense, the molecules are closer together thus allowing for less mechanical absorption of the sound waves.

The variations in the results from day to day are directly attributed to two problems. The first problem occurred with the instability of the readings on the oscilloscope. This problem was most prominant in the first fifteen to twenty seconds of a given test period. The second problem arose from the difficulty in aligning the transmitter and reception heads on the horizontal plane. If this procedure was not executed properly, there would result a greater degree of refraction and reflection, thereby producing lower reception percentages.

This procedure becomes more important when it is realized that the dismantling procedure was repeated after every five minutes of the testing period for the first five test days. This procedure

This procedure was to insure that the heads were cooled to twenty-one degrees centigrade.

Finally, the variation from day to day was not significant, thus no further statistical procedures were required for the interuption of the results.

CHAPTER V

SUMMARY AND CONCLUSIONS

Purpose

The purpose of this study was to determine the degree to which a representative sample of commonly used coupling agents assist in the transmission of ultrasound at a frequency of eight hundred and seventy kilocycles emitted through a range of predetermined intensities.

Hypothesis

The following null hypothesis was assumed throughout the study.

1. There is no difference in the sound conduction qualities of the five coupling agents - symbolically $U_1 = U_2 = U_3 = U_4 = U_5$.

Procedures

The pre-test procedures included the following steps. Firstly, the coupling agents were poured into small beakers which in turn were placed in a water bath. The function of the water bath was to maintain the coupling agents at a constant 21 degrees centigrade. A thermocouple was used to periodically check that this temperature was constant. Secondly, the receiver head was mounted and the ultrasound unit was turned on allowing it to warm-up for two minutes prior to the start of each testing day.

The in-test procedures involved the following steps. Firstly, the coupling agent was applied to the receiver head. Secondly, the transmitter head was secured in the housing such that the two heads were in a direct vertical alignment located three decimal one five millimeters apart. Thirdly, the desired intensity was set on the ultrasound unit with the contact switch depressed. When the switch was opened there appeared on the oscilloscope an electrical interpretation of the transmitted and reception intensity. Finally, the results illustrated on the oscilloscope were recorded every minute for a total of five minutes. At the completion of the fifth minute, a photograph was taken in order to assist in the verification of the results. The above procedures were repeated for all coupling agents at all intensities for all five days.

Finally, the post-test procedures involved dismantling the head arrangement such that the accumulation effect of the coupling agents and the heat build up could not affect the results.

Results

The results indicated that a coupling agent is necessary since the absence of a coupling agent resulted in no reception of sound while using the sensitivity setting of twenty volts per centimeter.

Specifically, the results indicated that the null hypothesis is rejected - symbolically $U_1 \neq U_2 \neq U_3 \neq U_4 \neq U_5$.

The results recorded at an intensity of 0.7 watts per square centimeter are listed in Table IX.

TABLE IX

THE MEAN PERCENTAGES OF SOUND RECEPTION OF THE FIVE COUPLING AGENTS AT AN INTENSITY OF 0.7 WATTS PER SQUARE CENTIMETER

Coupling Agent	Daily Average 1	2	3	4	5	Weekly Average
Thixotrophic Gel	63.33	66.94	75.00	72.22	65.14	68.53
Cardiac Gel	33.61	27.71	19.43	25.56	23.33	25.93
Distilled Water	53.00	45.29	63.16	56.30	56.67	54.88
Glycerine	60.98	67.38	69.05	66.67	66.05	66.02
Liquid Petroleum	18.75	21.88	20.00	21.88	18.75	20.25

The results from Table IX indicate that thixotrophic gel transmitted the highest percentage of sound.

The results recorded at an intensity of 1.4 watts per square centimeter are listed in Table X.

TABLE X

THE MEAN PERCENTAGES OF SOUND RECEPTION OF THE FIVE COUPLING AGENTS AT AN INTENSITY OF 1.4 WATTS PER SQUARE CENTIMETER

Coupling Agent	Daily Average 1	2	3	4	5	Weekly Average
Thixotrophic Gel	70.00	73.26	73.91	72.34	69.78	71.86
Cardiac Cream	22.09	30.23	20.23	29.55	22.05	24.33
Distilled Water	57.14	52.31	60.00	62.50	61.00	58.59
Glycerine	64.00	64.60	69.23	68.00	66.15	66.40
Liquid Petroleum	16.98	19.07	18.33	18.60	16.05	17.81

The results of Table X at an intensity of 1.4 watts per square centimeter are in the same sequence as the results in Table VIII. When the intensity was doubled, all the average weekly percentages increased, except those for cardiac cream and liquid petroleum.

TABLE XI

THE MEAN PERCENTAGES OF SOUND RECEPTION OF THE FIVE COUPLING AGENTS AT AN INTENSITY OF 2.1 WATTS PER SQUARE CENTIMETER

Coupling Agent	Daily Average 1	2	3	4	5	Weekly Average
Thixotrophic Gel	73.20	73.85	75.00	75.96	71.54	73.91
Cardiac Cream	21.60	28.40	19.00	31.80	23.80	24.92
Distilled Water	61.46	61.22	61.22	58.33	61.87	60.82
Glycerine	68.52	65.45	65.93	66.36	66.67	66.59
Liquid Petroleum	16.33	20.21	19.15	18.75	16.33	18.15

The same sequence of results was also evident in Table XI with all the coupling agents exhibiting an increase over the results recorded in Table X.

The results in Table XII illustrate the same sequence as in Tables IX, X, and XI with the following coupling agents exhibiting an increase in percentage of sound reception over the results indicated in Table X: cardiac cream, glycerine, and liquid petroleum.

TABLE XII

THE MEAN PERCENTAGES OF SOUND RECEPTION OF THE FIVE COUPLING AGENTS AT AN INTENSITY OF 2.8 WATTS PER SQUARE CENTIMETER

Coupling Agent	Daily Average					Weekly Average
	1	2	3	4	5	
Thixotrophic Gel	72.04	74.07	73.52	75.93	72.41	73.59
Cardiac Cream	36.23	31.73	29.81	34.42	22.64	30.97
Distilled Water	62.31	65.58	62.50	60.38	61.54	62.46
Glycerine	72.96	67.86	71.07	66.07	67.27	69.05
Liquid Petroleum	17.50	21.57	19.23	19.80	16.92	19.01

TABLE XIII

THE MEAN PERCENTAGES OF SOUND RECEPTION OF THE FIVE COUPLING AGENTS AT AN INTENSITY OF 3.5 WATTS PER SQUARE CENTIMETER

Coupling Agent	Daily Average					Weekly Average
	1	2	3	4	5	
Thixotrophic Gel	76.23	78.90	69.82	76.36	74.44	75.15
Cardiac Cream	23.33	32.26	26.30	28.52	23.70	26.82
Distilled Water	61.11	65.09	64.63	59.44	60.56	62.17
Glycerine	70.37	70.54	70.80	71.43	70.36	70.70
Liquid Petroleum	19.23	21.15	20.75	21.15	18.11	20.08

As in the other tables, Table XIII illustrated the same sequence of results with the following coupling agents exhibiting an increase: thixotrophic gel, glycerine, and liquid petroleum.

It was evident from the results that some variation existed from day to day. This variation can be explained by two phenomena. Firstly, the reading on the oscilloscope could not be stabilized immediately. This instability was evident for the first fifteen seconds of the first minute, but on occasion, it continued for more than a minute. To further complicate the issue, the value of each centimeter on the grid was valued at 20 volts. Therefore, an accurate reading was, on occasion, difficult to determine.

Secondly, it was difficult to determine when the transmitter and reception heads were in horizontal alignment. If this alignment was not exact, the reflection and refraction of the sound was drastically increased. The inalignment phenomenon becomes critical when it is realized that after every five minutes, the heads were dismantled so they could be cleaned and cooled. This procedure was necessary in order to maintain the temperature to the heads within the clinical range.

Conclusions

Within the limitations of the study, the following conclusions were made:

1. The coupling agent which ranked the best conductor of sound at the five intensities was thixotrophic gel.

2. Glycerine was consistently ranked as second at all five intensities.

3. Distilled water was consistently the third best at all five intensities.

4. The fourth best conductor of sound was cardiac cream.

5. The fifth best conductor of sound was liquid petroleum.

6. Generally, as the intensity was increased by intervals of 0.7 watts per square centimeter (continuous wave) the weekly averages of thixotrophic gel, glycerine and distilled water also increased. However, this finding was not consistent with cardiac cream and liquid petroleum.

7. Finally, it was concluded that all five coupling agents are not equal in respect to their ability to transmit ultra-sound at a continuous wave setting.

Recommendations

The following recommendations are based on the results of this study and are in reference to the clinical situation.

1. Thixotrophic gel should be used for all treatments of ultrasound.

2. If thixotrophic gel is not available, glycerine would be a satisfactory substitute.

3. In cases where the area being treated does not lend itself to a good and consistent contact between the transmitter head and the coupling agent, water should be used (emmersion technique).

4. In the translation of prescriptions for ultrasound, an adjustment should be made for the shortcomings of the coupling agent being used.

5. The mathematics of the half-valve layer theorem suggests that the intensity recorded on the machine is the same as that which is found prior to entering the skin. It seems that it is assumed that there is no loss of intensity as the sound passes through the coupling agent. On the basis of this study, adjustments must be made for the absorption of sound by the coupling agents, when calculating depth of penetration.

Further Research

1. Further research is required to develop a coupling agent that will transmit a higher percentage of sound.

2. If the same measurement technique is used as was done in this study, the problem of alignment of the heads must be overcome.

3. In the light of the data there is a need for a re-review of literature since most studies assume one hundred percent transmission.

4. Include more samples in order to broaden the application of the results.

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APPENDIX A

COMPUTER PROGRAM

A computer program was written to accomplish all compilations, conversion of raw scores to percentages, and list the results as tables. Fortran IV computer language was used at the Northern Alberta Institute of Technology. The actual program is not available other than by request and therefore is listed below.

MS FORTRAN (4.0)/MSOS

```
      PROGRAM THESIS
      DIMENSION HEADA(50, MEADB(30), A(6), B(6), C(6), D(6), E(6), F(6)
      HEADA(1)=0.7
      HEADA(2)=1.4
      HEADA(3)=2.1
      HEADA(4)=2.8
      HEADA(5)=3.5
      MEADB(1)=4H AIR
      MEADB(2)=4H
      MEADB(3)=4H
      MEADB(4)=4H
      MEADB(5)=4H
      MEADB(6)=4H AQU
      MEADB(7)=4HASON
      MEADB(8)=4HIC G
      MEADB(9)=4HELET
      MEADB(10)=4HIN
      MEADB(11)=4HCAR
      MEADB(12)=4HDIAC
      MEADB(13)=4H CRE
      MEADB(14)=4HAM
      MEADB(15)=4H
      MEADB(16)=4H DIS
      MEADB(17)=4HTILL
      MEADB(18)=4HED W
      MEADB(19)=4HATER
      MEADB(20)=4H
      MEADB(21)=4H GLY
      MEADB(22)=4HCERI
      MEADB(23)=4HNE
      MEADB(24)=4H
      MEADB(25)=4H
      MEADB(26)=4H LIQ
      MEADB(27)=4HUID
      MEADB(28)=4HPETR
      MEADB(29)=4HOLEU
      MEADB(30)=4HM
      DO 100 I=1,5
      A2=B2=C2=D3=E2=F2=0
      WRITE (61,2) HEADA(I)
    2 FORMAT (1H1,45X,13HINTENSITY     ,F3.1.28H WATTS PER SQUARE CENTIM
     1ETTER)
      WRITE (61,3)
    3 FORMAT (1H0,14HCOUPLING AGENT,14X,5HDAY 1,15X,5HDAY 2,15X,5HDAY 3,
     115X,5HDAY 4,15XDAY 5,12X,10H5 DAY AVG.,/)
```

```
      K1=1
      DO 150 K-1,6
      K2=K1+4
      READ (60,4) A1,(A(N),N=1,5),B1,(B(M),M=1,5),C1,(C(L),L=1,5)
      READ (60,4) D1,(D(N),N=1,5),E1,(E(j),J=1,5),
      4  FORMAT (F3.0,5(F2.0))
         A(6)=B(6)=C(6)=D(6)=E(6)=F(6)=0
         DO 200 J=1,5
         A(J)=(A(J)/A1)*100
         B(J)=(B(J)/B1)*100
         C(J)=(C(J)/C1)*100
         D(J)=(D(J)/D1)*100
         E(J)=(E(J)/E1)*100
  200 CONTINUE

         DO 300 J=1,5
         F(J)=(A(J)+B(J)+C(J)+D(J)+E(J))/5
  300 CONTINUE
C
         DO 400
         J=1,5
         A(6)=A(6)+A(J)
         B(6)=B(6)=B(J)
         C(6)=C(6)=C(J)
         D(6)=D(6)=D(J)
         E(6)=E(6)=E(J)
         F(6)=F(6)=F(J)
C
         A2=A2+A(J)
         B2=B2+B(J)
         C2=C2+C(J)
         D2=D2+D(J)
         E2=E2+E(J)
         F2=F2=A(J)+B(J)+C(J)+D(J)+E(J)
  400 CONTINUE
C
         A(6)=A(6) /5
         B(6)=B(6) /5
         C(6)=C(6) /5
         D(6)=D(6) /5
         E(6)=E(6) /5
         F(6)=F(6) /5
C
         WRITE (61,5) (MEADB(J),J=K1,K2),A(1),B(1),C(1),D(1),E(1),F(1)
      5  FORMAT (1H ,5A4,8X,F5.2,5(15X,F5.2))
         K1=K2=1
         DO 500 J=2,5
         WRITE (61,6) A(J),B(J),C(J), D(J),E(J),F(J)
      6  FORMAT (1H ,28X,F5.2,15X,F5.2,15X,F5.2,15X,F5.2,15X,F5.2,15X,F5.2)
```

```
500 CONTINUE
      WRITE (61,7) A(6),B(6),C(6), D(6),E(6),F(6)
   7  FORMAT (1H0,19X,7HAVERAGE,2X,F5.2,15X,F5.2,15X,F5.2,15X,F5.2,15X,F
     15.2,15X,F5.2//)
150 CONTINUE
      A2=A2/25
      B2=B2/25
      C2=C2/25
      D2=D2/25
      E2=E2/25
      F2=F2/25
      WRITE (61,8) A2, B2, C2, D2, E2, F2
   8  FORMAT (1H0,18H DAILY AVERAGE    ,10X,F5.2,5(15X,F5.2))
100   CONTINUE
      WRITE (61,9)
   9  FORMAT (1H1)
      STOP
      END
```

FORTRAN DIAGNOSTIC RESULTS FOR THESIS

APPENDIX B

RAW DATA

In the following tables, the first number of each sequence represents the transmitted voltage, while the next five numbers are the voltages received at minute one, two, three, four and five respectively.

TABLE XIV

RAW SCORES RECORDED FOR THE FIVE COUPLING AGENTS AT AN INTENSITY OF 0.7 WATTS PER SQUARE CENTIMETER

Coupling Agent	Days				
	1	2	3	4	5
Air	68-0,0,0,0,0	60-0,0,0,0,0	60-0,0,0,0,0	64,0,0,0,0,0	64-0,0,0,0,0
C.A.-1	60-38,38,38,38,38,	72-48,48,48,48,49	72-54,54,54,54,54	72-52,52,52,52,52	70-44,46,46,46,46
C.A.-2	72-20,24,24,25,28	70-10,16,21,24,26	70-12,17,15,12,12	72-18,18,19,19,18	72-14,16,18,18,18
C.A.-3	60-31,32,32,32,32	68-30,31,31,31,31	76-48,48,48,48,48	54-30,30,30,30,32	60-36,36,34,32,32
C.A.-4	82-50,50,50,50,50,	84-56,56,57,57,57	84-58,58,58,58,58	84-56,56,56,56,56	86-58,58,56,55,57
C.A.-5	64-12,12,12,12,12	64-14,14,14,14,14	60-12,12,12,12,12	64-14,14,14,14,14	64-12,12,12,12,12

CODE

C.A.-1	Thixotrophic Gel
C.A.-2	Cardiac Cream
C.A.-3	Distilled Water
C.A.-4	Glycerine
C.A.-5	Liquid Petroleum

TABLE XV

RAW SCORES RECORDED FOR THE FIVE COUPLING AGENTS AT AN INTENSITY OF 1.4 WATTS PER SQUARE CENTIMETER

Coupling Agent	1	2	3	4	5
Air	85-0,0,0,0,0	84-0,0,0,0,0	80-0,0,0,0,0	88-0,0,0,0,0	82-0,0,0,0,0
C.A.-1	92-55,65,64,64,64,	92-68,68,68,67,66	92-68,68,68,68,68	94-68,68,68,68,68	92-65,64,64,64,64
C.A.-2	86-20,22,21,16,16	88-24,26,25,26,32	88-16,18,17,16,22	88-26,26,26,26,26	88-22,22,16,18,19
C.A.-3	84-48,48,48,48,48	65-34,34,34,34,34	85-50,50,51,52,52	80-50,50,50,50,50	80-48,49,49,49,49
C.A.-4	100-64,64,64,64,64	100-65,66,64,64,65	104-72,72,72,72,72	100-68,68,68,68,68	104,70,70,68,68,68
C.A.-5	86-15,15,15,15,13	86-16,16,16,17,17	84-15,15,16,15,16	86-16,16,16,16,16	86-15,15,13,13,13

<u>CODE</u>

C.A.-1	Thixotrophic Gel
C.A.-2	Cardiac Cream
C.A.-3	Distilled Water
C.A.-4	Glycerine
C.A.-5	Liquid Petroleum

TABLE XVI

RAW SCORES RECORDED FOR THE FIVE COUPLING AGENTS AT AN INTENSITY OF 2.1 WATTS PER SQUARE CENTIMETER

Coupling Agent	1	2	3	4	5
Air	92-0,0,0,0,0	94-0,0,0,0,0	92-0,0,0,0,0	98-0,0,0,0,0	94-0,0,0,0,0
C.A.-1	100-68,74,74,74,76	104-76,76,76,76,80	104-78,78,78,78,78	104-79,79,79,79,79	104-74,74,76,76,72
C.A.-2	100-21,21,22,22,22	100-28,32,32,30,20	100-16,17,16,24,22	100-32,32,32,31,32	100-21,22,23,26,27
C.A.-3	96-60,59,59,58,59	98-60,60,60,60,60	98-60,60,60,60,60	96-56,56,56,56,56	96-60,60,59,59,59
C.A.-4	108-74,74,74,74,74	110-72,72,72,72,72	108-68,72,72,72,72	110-73,73,73,73,73	108-72,72,72,72,72
C.A.-5	98-16,16,16,16,16	96-18,19,20,20,20	94-18,18,18,18,18	96-18,18,18,18,18	98-16,16,16,16,16

CODE

C.A.-1	Thixotrophic Gel
C.A.-2	Cardiac Cream
C.A.-3	Distilled Water
C.A.-4	Glycerine
C.A.-5	Liquid Petroleum

TABLE XVII

RAW SCORES RECORDED FOR THE FIVE COUPLING AGENTS AT AN INTENSITY OF 2.8 WATTS PER SQUARE CENTIMETER

Coupling Agents	1	2	3	4	5
Air	104-0,0,0,0,0	104-0,0,0,0,0	102-0,0,0,0,0	104-0,0,0,0,0	104-0,0,0,0,0
C.A.-1	108-78,78,78,77,78	108-80,80,80,80,80	108-80,80,80,79,78	108-82,82,82,82,82	108-78,78,77,79,79
C.A.-2	106-38,40,40,42,32	104-32,33,33,33,34	108-28,32,37,34,30	104-34,36,36,37,36	106-22,24,24,25,25
C.A.-3	104-66,66,64,64,64	104-68,69,68,68,68	104-62,65,65,66,67	104-66,62,62,62,62	104-64,64,64,64,64
C.A.-4	108-76,78,80,80,80	112-76,76,76,76,76	112-80,80,80,79,79	112-74,74,74,74,74	110-74,74,74,74,74
C.A.-5	104-18,18,18,18,19	102-22,22,22,22,22	104-20,20,20,20,20	102-18,20,20,21,22	104-18,18,18,17,17

CODE

C.A.-1	Thixotrophic Gel
C.A.-2	Cardiac Cream
C.A.-3	Distilled Water
C.A.-4	Glycerine
C.A.-5	Liquid Petroleum

TABLE XVIII

RAW SCORES RECORDED FOR THE FIVE COUPLING AGENTS AT AN INTENSITY OF 3.5 WATTS PER SQUARE CENTIMETER

Coupling Agent	1	2	3	4	5
Air	106-0,0,0,0,0	106-0,0,0,0,0	106-0,0,0,0,0	108-0,0,0,0,0	106-0,0,0,0,0
C.A.-1	106-80,82,82,80,80	109-89,89,88,84,80	112-79,78,78,78,78	110-84,84,84,84,84	108-82,80,80,80,80
C.A.-2	108-26,28,24,24,24	106-36,34,33,34,34	108-34,28,24,32,24	108-30,31,31,30,32	108-28,24,24,26,26
C.A.-3	108-68,66,66,66,64	106-72,71,68,66,68	108-69,70,70,70,70	108-68,66,65,62,60	108-69,66,64,64,64
C.A.-4	108-76,76,76,76,76	112-79,79,79,79,79	113-80,80,80,80,80	112-80,80,80,80,80	112-78,79,79,79,79
C.A.-5	104-20,20,20,20,20	104-22,22,22,22,22	106-22,22,22,22,22	104-22,22,22,22,22	106-20,20,20,18,18

CODE

C.A.-1	Thixotrophic Gel
C.A.-2	Cardiac Cream
C.A.-3	Distilled Water
C.A.-4	Glycerine
C.A.-5	Liquid Petroleum